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Comparative studies on optical parameters of CdTe and ZnO thin films

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Abstract : The optical parameters of vacuum evaporated (p)CdTe and (n)ZnO thin films were studied and compared using uv-visible spectrophotometer equipped with an integrating sphere. The main optical parameters studied are: transmittance, reflectance, absorbance, refractive index, extinction co-efficient *etc*. Comparison at wavelength 500 nm shows that refractive index *'n'* as well as imaginary part of dielectric constant, 'ε''' of (n)ZnO films are smaller than that of (*p*) CdTe films which indicates the more transparency of (*n*)ZnO films and more efficient semiconductor for using as transparent conducting oxide (TCO) in most of the junction devices. Static (dc) electrical conductivity is observed to increase slowly towards the IR spectrum as imaginary part of refractive index *'k'* increases towards higher wavelength.

Keywords : Activation energy, complex dielectric constant, extinction coefficient, TCO

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1. Introduction

ZnO is found as a good candidate of transparent conducting oxide (TCO) and therefore can substitute indium tin oxide (In_2O_3: Sn) and tin oxide (SnO_2) in conductive electrodes of other semiconductor solar cells. Due to its high stability [1] in hydrogen plasma, strain free, nontoxicity, controllable resistivity and low cost of the constituent elements make ZnO very attractive for photovoltaic applications [2]. On the other hand CdTe (energy gap [3] =1.5 eV) an II-VI intermetallic compound is a direct band gap semiconductor. It has a high absorption co-efficient, which is required for good theoretical conversion efficiency. This has led to the investigation of CdTe based heterojunctions and Schottky Barrier devices for using as photovoltaic (PV) devices. The *I-V* characteristics under illumination of the ZnO/CdTe/Ag junction were reported [4] without PV efficiency calculation. Sputter-

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deposited (n)ZnO on (p)Zn_3P_2 devices have been reported [5] with PV efficiencies of only 2.0%. A thin film ZnO/p-CdTe photovoltaic device, which showed an efficiency of 3.7% was reported [6]. Recently PV efficiency of vacuum deposited (p) CdTe/(n)ZnO heteorojunction has been reported [7,8] to be 4.01% using hydrogenation for $N_a = 1.03 \times 10^{15}$ cm^{-3} $N_d = 9.95 \times 10^{14}$ cm^{-3}.

2. Experiment

Films of equal area (1.5 x 1.5) cm^2 of pure CdTe powder (99.999%, Aldrich Chem. Co., USA) mixed with 2.53% of Sb and ZnO powder (99.995%, Aldrich Chem. Co., USA) mixed with 4.08% of Al were deposited by thermal evaporation from a molybdenum boat on chemically cleaned glass substrates under pressure 10^{-5} Torr. The substrate temperature was maintained at 423 K at the time of film deposition. The films were then annealed for 5 hours allowing maximum temperature of 528 K and maintaining the pressure at 10^{-4} Torr. For transmittance, absorbance and reflectance measurement, Cary-300 Scan uv-visible spectrophotometer (Varian, Victoria-3170, Australia) was used. The measurement of the type and carrier concentrations were carried out by the traditional technique involving Hall effect and *C-V* measurements on the structures of Al/(p)CdTe and Sn/(n)ZnO Schottky junctions were also made.

3. Result and discussion

The optical transmittance *(T)* and absorbance *(A)* spectra of a typical (p)CdTe and (n)ZnO annealed films have been shown in Figure 1 and Figure 2 respectively. In both the cases absorbance has its maximum value at the higher energy and decreases with lower energy towards the visible region.

Absorption coefficients in the interference-free region were calculated from relation [9],

$$\frac{T_1}{T_2} = \exp\left[\alpha\left(t_2 - t_1\right)\right] \tag{1}$$

where, T_1 and T_2 the transmittances for the samples of thickness t_1 and t_2 respectively and α, the absorption coefficient. Since CdTe is a direct band gap semiconductor, its band gap was determined from $(h\nu\alpha)^2$ *versus* $h\nu$ plots using relation [10],

$$\alpha h\nu = B\left(h\nu - E_g\right)^{1/2} \tag{2}$$

Figure 1(c) gives a typical plot of $(\alpha h\nu)^2$ *versus* $h\nu$ for (p)CdTe film from which extrapolation of data to the $(\alpha h\nu)^2 \to 0$ axis gives the band gap energy E_g = 1.564 eV and for annealed (n)ZnO film, this value is 3.35 eV [Figure 2(c)].

Values of refractive index *(n)* of (p)CdTe thin film in the interference zone at all transmittance minima [Figure1(a)] were determined from the relation [11],

$$T_{\min} = 6n^2 \Big/ \left(n^4 + 3.25n^2 + 2.25\right) \tag{3}$$

and in the interference-free region by extrapolation of the n values obtained in the interference region using Cauchy's dispersion relation,

$$n = A + B/\lambda^2 \tag{4}$$

where, A and B are constants and can be obtained from the n versus $1/\lambda^2$ plots [Figure 1(d) and 2(d)].

From the knowledge of α, the extinction coefficient k ($k = \alpha\lambda/4\pi$) and then real and

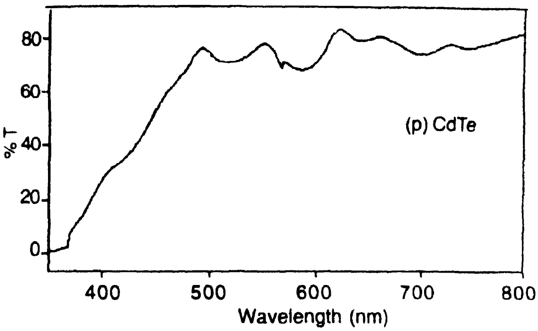

Figure 1(a). Transmission spectra of annealed (p)CdTe film

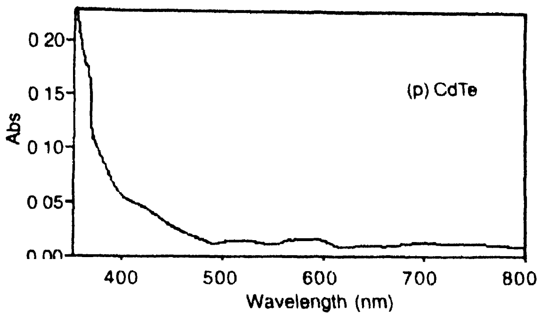

Figure 1(b) Absorption spectra of annealed (p)CdTe film

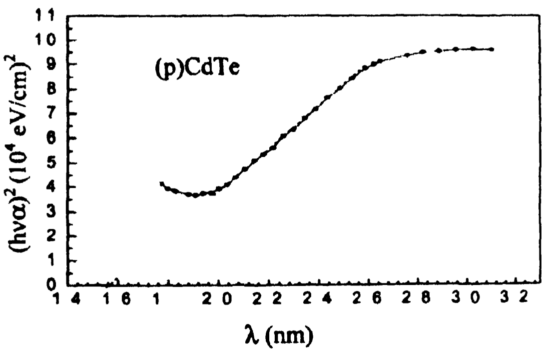

Figure 1(c). $(h\nu\alpha)^2$ *versus* $h\nu$ plots of (p)CdTe film

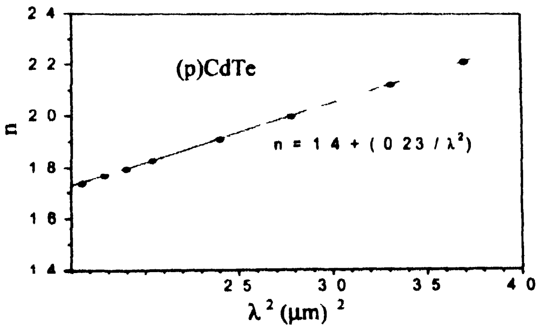

Figure 1(d). n *versus* λ^{-2} plots of (p)CdTe film

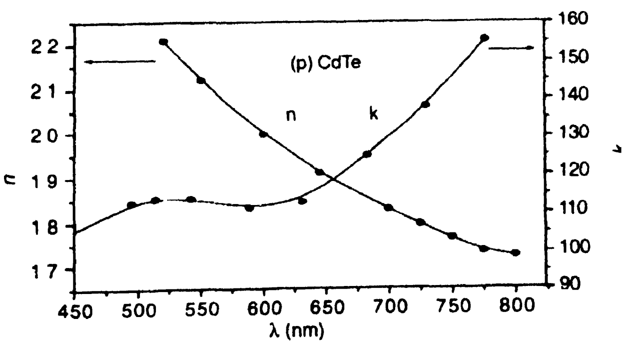

Figure 1(e). n and k *versus* λ plots of (p)CdTe film imaginary parts of the dielectric constants ε' and ε'' were calculated using relations [12],

$$\varepsilon' = n^2 - k^2 \tag{5}$$

and
$$\varepsilon'' = 2nk = \frac{4\pi\sigma}{\omega} \tag{6}$$

respectively

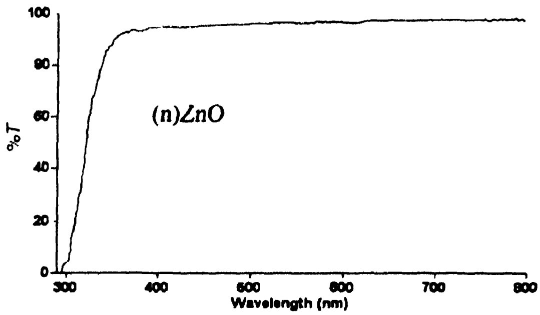

Figure 2(a). Transmission spectra of annealed (n)ZnO film

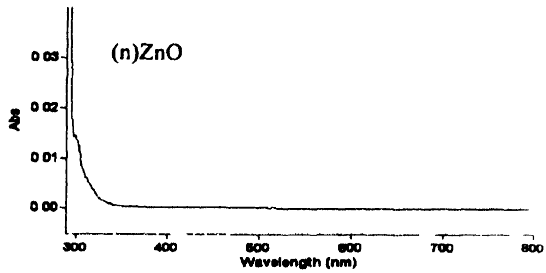

Figure 2(b). Absorption spectra of annealed (n)ZnO film

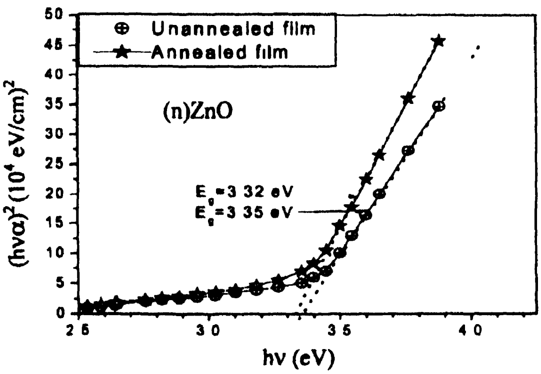

Figure 2(c). $(h\nu\alpha)^2$ *versus* $h\nu$ plots of (n)ZnO film

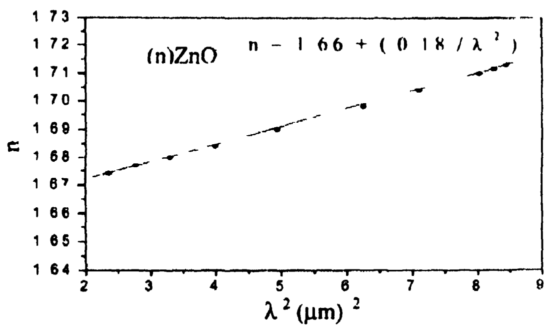

Figure 2(d). *n versus* λ^{-2} plots of (n)ZnO film

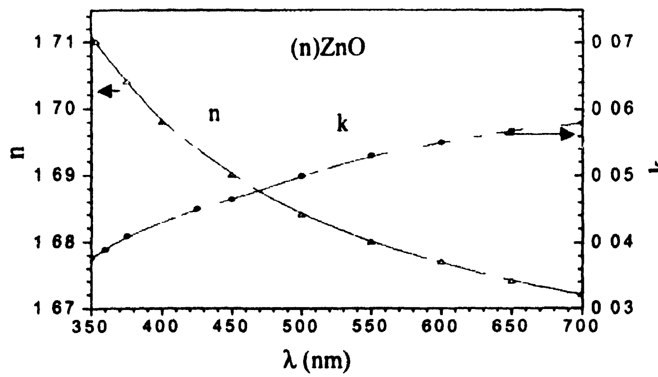

Figure 2(e). n and *k versus* λ plots of (n)ZnO film

Where, ω is the angular frequency of the incident light and σ is the static (dc) electrical conductivity

Variations of *n* and *k* with wavelength have been shown in Figure 1(e) and Figure 2(e) Normal dispersion is pronounced in both the cases The change of imaginary part of refractive index (*k*) with wavelength is found to be interesting phenomena in (p)CdTe films Imaginary part of refractive index, *k* (and so, imaginary part of dielectric constant, ε'') is observed to increase slowly up to the wavelength 550 nm, slows down to 625 nm and then increases rapidly towards the IR region [Figure 1(e)] However, it increases slowly in case of ZnO films These show that static (dc) electrical conductivity of both (p)CdTe and (n)ZnO films increase towards the IR spectrum[12] Values of some optical parameters of typical (p)CdTe and (n)ZnO films are shown in Table 1 and 2 respectively The comparison chart of some optical parameters of these films for same order of doping concentration and at same wavelength (500 nm) has been shown in Table 3 Comparison at wavelength

Table 1 Values of some optical parameters of a typical (p)CdTe film (doping concentration N_a - 2 87 x 10^{16} cm^{-3}) for film thickness 5304 Å

λ (nm)	T%	n	α (10^4 cm^{-1})	k (10^{-3})	ε'	ε''	E_g(eV)
400	27 324	2 838	3 10	98 676	8 045	0 560	
450	54 336	2 504	3 06	109 578	6 744	0 544	
500	75 436	2 320	2 83	112 602	5 369	0 522	
550	78 134	2 120	2 60	113 796	4 481	0 482	1 56
600	70 232	1 997	2 33	111 249	3 976	0 444	
650	80 054	1 948	2 18	112 761	5 095	0 509	
700	75 587	1 725	2 24	124 777	3 972	0 498	
800	84 044	1 725	2 44	155 335	2 952	0 536	

Table 2. Values of some optical parameters of a typical (n)ZnO film (doping concentration N_d = 2 28 x 10^{17} cm^{-3}) for film thickness 3050Å

λ (nm)	T%	n	α (10^4 cm^{-1})	k	ε'	ε''	E_g(eV)
350	89 286	1 710	1 364	0 038	2 922	0 129	
400	94 805	1 698	1 319	0 042	2 881	0 143	
450	95 129	1 690	1 285	0 046	2 853	0 155	3 35
500	95 779	1 684	1 257	0 050	2 833	0 169	
550	96 428	1 680	1 211	0 053	2 819	0 178	
600	96 429	1 677	1 152	0 055	2 809	0 184	
650	97 362	1 674	1 121	0 058	2 799	0 194	

500 nm shows that refractive index *n* as well as imaginary part of dielectric constant, ε'' of (n)ZnO films is smaller than that of (p)CdTe film which indicates more transparency of (n)ZnO film. This indicates that (n)ZnO is more efficient semiconductor for using as transparent conducting oxide (TCO) as well as window layers in most of the junction devices.

Table 3. Comparison of some optical parameters of typical (p)CdTe, and (n)ZnO films (for same order of doping concentration and in same wavelength =500 nm).

Sample	N (10^{16}cm^{-3})	σ (Ω^{-1} cm^{-1})	α (cm^{-1})	n	ε'	ε''
(p)CdTe	2.87	8.47×10^{-8}	2.83×10^{4}	2.32	5.37	0.52
(n)ZnO	2.88	3.37×10^{-7}	1.26×10^{4}	1.68	2.83	0.17

4. Conclusion

Optical parameters of vacuum deposited CdTe and ZnO thin films have been determined and compared. Higher absorption coefficient has been observed in (p)CdTe film, which is required for a good conversion efficiency and has led to the investigation of CdTe-base heterojunctions and Schottky barrier devices for its use as a photovoltaic (PV) device. On the other hand lower refractive index of (n)ZnO film in comparison to (p)CdTe indicates that (n)ZnO is more efficient semiconductor for using as transparent conducting oxide (TCO) in most of the junction devices.

References

[1] B Joseph, K G Gopchandran, P K Manoj, P Koshy and V K Vaidyan *Bull. Mater. Sci.* **22** 921 (1999)

[2] K L Chopra, S Manoj and D K Pandya *Thin Solid Film* **102** 1 (1983)

[3] J J Lofesrki *J. Appl. Phys.* **27** 777 (1956)

[4] B R Mehta, S Kumar, K Singh and K L Chopra *Thin Solid Films* **164** 265 (1988)

[5] K W Mitchell *Physics of Solar Cells*, (eds.) S C Join, S Radhakrishna and T R S Reddy (1st edition) (International Council of Scientific Union, Madras, India) 159 (1984)

[6] M S Tomar *Thin Solid Films* **164** 295 (1988)

[7] G Wary, T Kachary and A Rahman *Intl. J. Thermophysics* **27** 332 (1) (2006)

[8] G Wary, T Kachary and A Rahman *Indian J. Pure & Appl. Phys.* **Vol. 44** 754 (2006)

[9] F Abeles *Optical Properties of Solids* 23 (Amsterdam : North Holand Publishing Co.) (1972)

[10] J I Pankove *Optical Processes in Semi-conductors* pgs. 36, 94 (New York : Dover Publications, Inc) (1971)

[11] I Martil and G Gonzalez Diaz *Am. J. Phys.* **60(1)** 83 (1992)

[12] K L Chopra *Thin Film Phenomena* pgs. 729, 734 (New Work : MacGraw Hill Book Co.) (1969)